# CHAPTER EIGHT

# MANUFACTURING TECHNOLOGY

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# MANUFACTURING TECHNOLOGY

## OBJECTIVE

This chapter describes the role and impact of manufacturing technology on the systems acquisition process. Manufacturing process evaluation and selection establish the manufacturing cost and risk. The chapter treats both the physical processes and management structure in which process decisions are made. The impact of and tools for encouraging industrial modernization are described. Emphasis is also placed on the impact on computers on process selection and control to prepare the Program Manager (PM) to deal with their program impacts.

## INTRODUCTION

Manufacturing processes are the activities which change the form or properties of materials to give them the physical and functional characteristics which are required by the end item design. To achieve production phase objectives it is necessary to use efficient, shop-proven processes for material transformation. These two process descriptors — efficient and shop-proven — often tend to be mutually exclusive. New processes and new approaches to manufacturing execution, such as computer-aided manufacturing, often do not have extensive shop experience. The challenge to the PMO is to obtain maximum efficiency of manufacture within the risk levels deemed acceptable for the specific program. This chapter identifies some of the mechanisms for describing and proofing manufacturing processes. There is also a discussion of the integration of advanced manufacturing technology into the manufacturing program. It is important to recognize that advanced manufacturing technology generally brings certain levels of risk to a program along with the potential benefits of improved efficiency.

## PROCESS PLANNING AND SELECTION

In manufacturing planning, it is necessary to define the specific process which will be used in manufacturing the product. Part geometry, size, material to be used, number of parts to be produced and dollar value of the finished product are important factors to be considered. The variety of processes available for producing the part are

numerous, and selection of a particular process requires consideration of process capabilities and limitations in order to reduce the number of alternatives to a reasonable number for a final selection. The variety of processes available for metal fabrication, as an example, are illustrated in Figure 8-1.

| PROCURED ITEM COSTS | MATERIAL REMOVAL COSTS | DETAIL FABRICATION COSTS | MATERIAL TREATMENT COSTS | PERMANENT JOINING* COSTS | ASSEMBLY* COSTS |
|---|---|---|---|---|---|
| • FORGINGS<br>HAND<br>CONVENTIONAL<br>BLOCKER<br>PRECISION<br><br>• CASTING<br>SAND<br>PERMANENT MOLD<br>INVESTMENT<br>DIE CASTING<br><br>• EXTRUSIONS<br><br>• MATERIALS<br><br>• FASTENER SYSTEMS<br><br>• EMERGING PROC<br>ISOTHERMAL FORGING<br>POWDERED METAL<br>PULTRUSION<br>HIP HEALING<br>CAM | • MACHINING<br>TURNING<br>MILLING<br>DRILLING<br><br>• CHEM MILLING<br><br>• ELECTRO-DISCHARGE MACHINING<br><br>• ELECTRO-CHEMICAL MACHINING<br><br>• EMERGING PROC<br>LASER<br>FLUID-JET<br>CAM<br>EB CUTTING | • METALLIC<br>FORMING<br>CUTTING<br><br>• NON-METALLICS<br>FORMING<br>CUTTING<br>MOLDING<br>LAMINATING<br><br>• EMERGING PROC<br>SUPERPLASTIC FORMING<br>FLOW FORMING<br>HYDROSTATIC FORMING<br>THERMOPLASTIC FORMING<br>CAM | • HEAT TREATMENT<br><br>• SURFACE TREATMENT<br><br>• EMERGING PROC<br>LASER TREATING<br>NON-ENVIRONMENTAL POLLUTING TREATMENTS | • WELDING<br><br>• ADHESIVE BONDING<br><br>• BRAZING<br><br>• EMERGING PROC<br>DIFFUSION BONDING<br>WELD BONDING<br>LASER WELDING<br>ULTRASONIC WELDING<br>PLASMA ARC<br><br>* SUBASSEMBLY | • METALLIC ASSY<br>MECHANICAL FASTENING<br><br>• NON-METALLIC<br>MECHANICAL FASTENING<br><br>• EMERGING PROC<br>BIMETALLIC RIVETS<br>MICROWAVE CURING<br><br>* MAJOR AND FINAL ASSEMBLY |

**Figure 8-1 Manufacturing Processes Available for Metal Fabrication**

Process selection is based on the issues of economy, risk and the end application of the product. The choice of a process is based on several requirements. The following discussion provides an introduction to the process selection procedure based on design requirements.

Design Requirements

Design requirements constrain process selection by establishing performance requirements on the system and, by implication, on the individual parts. For example, metal parts which are highly stressed by directionally stable loads may require a forging operation so that the directional properties of the material can be aligned with the load paths.

Material Requirements

The choice of raw material will be determined by the mechanical characteristic desired. Ultimate strength, fatigue and corrosion properties often lead to the selection of specific materials. There may also be design limitations, such as weight and size, which constrain the material selection. If the material to be used is specified in the design package this often limits, or even dictates, the processes which can be used. Materials such as magnesium and titanium impose limitations on the choice of processes which can be used for their transformation due to the metals' special physical or chemical properties. For example, grinding or welding magnesium should be avoided due to the metal's flammability if not properly shielded from air or oxygen. Titanium tends to weld to steel surfaces of forming tools and is more easily formed at elevated temperatures. When materials thus limit the process selection, the cost of the processes can be extremely high. As another example, fracture toughness requirements in structures may lead to selection of a ceramic material, if brittleness is not a problem. Generally, the least expensive material which meets the requirement is chosen, but the impact of high cost processing may lead to selection of materials whose initial cost is higher, but whose total processing cost is less.

Finish Requirements

In most cases, the design engineer will specify a particular finish for the part. In the case of surface roughness, the impact of requirements on process selection is illustrated in Figure 8-2. As the smoothness requirement on metal parts becomes more stringent, the processing cost increases dramatically.

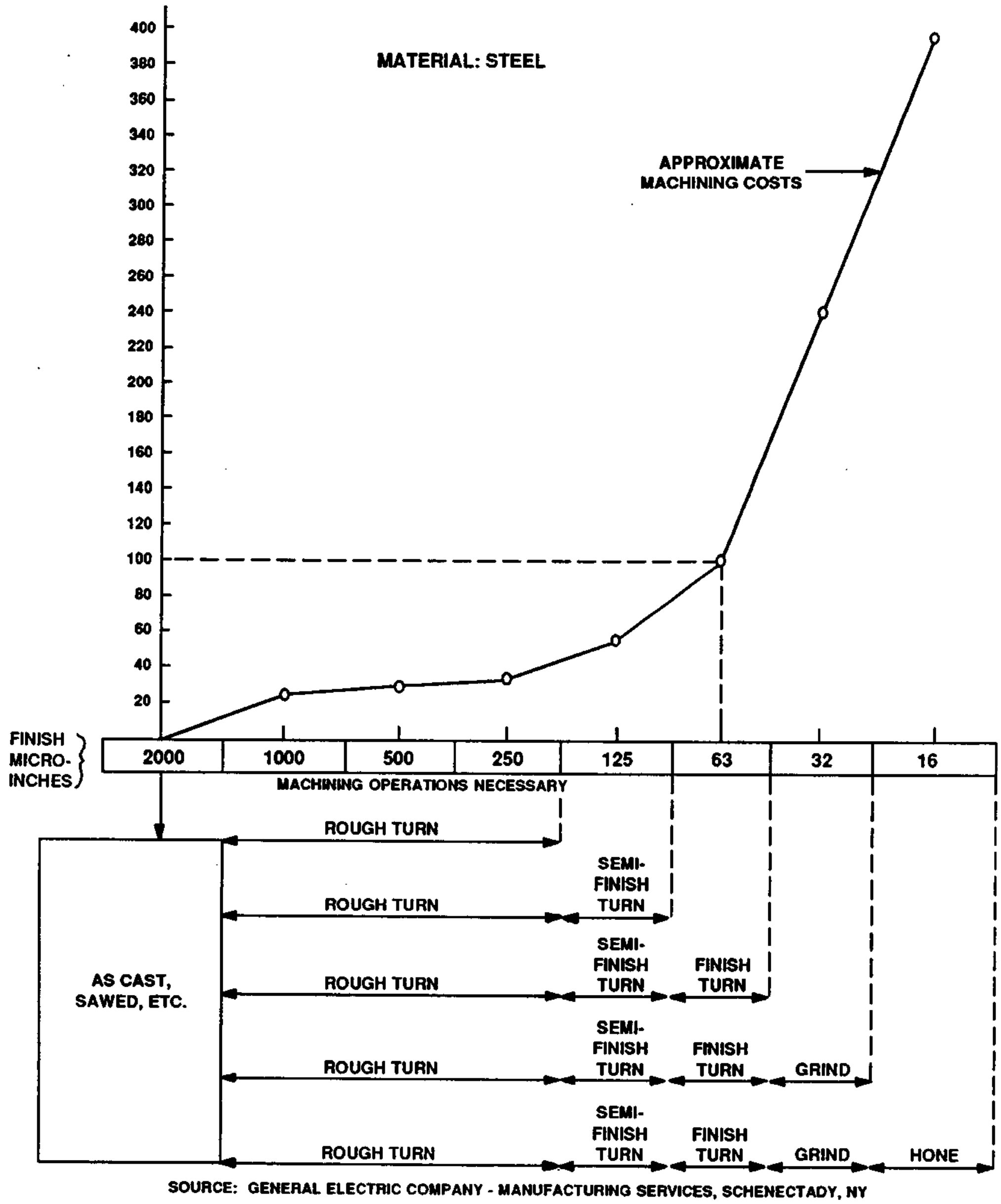


**Figure 8-2 Relative Machining Costs and Surface Finish**

Shape and Form

In the majority of manufacturing operations, parts go through a series of stages of processing. Manufacturing economies for metal parts can often be obtained through selection of appropriate initial product forms such as castings, forgings or extrusions. In electronic parts, economies can be obtained by utilizing denser integrated circuits, thus reducing the complexity of the circuit boards which accomplish the final performance function. In this regard, it is critical that the series of manufacturing steps to be used be considered in total to ensure that the cost of the total manufacturing sequence is optimized, rather than optimizing individual steps in the process.

Operation Sheets

After selection of processes to be used, process instructions must be communicated within the facility. In many firms, operation or route sheets are used to identify the processing methods for materials and parts through the manufacturing area, as well as to provide the authorization for requisitioning the necessary tools, materials, and parts. The operation sheet also provides the basis for detailed planning, estimating, and scheduling of the manufacturing effort. A completed process sheet will normally provide identification data including:

1. Part number. Engineering drawing number to identify the part.

2. Part name. Noun to aid in identifying of part.

3. Date. A record of when the document was prepared.

4. Drawing number. Provide a record for the part. Often, part numbers are based on a code to indicate relationships, such as subassemblies.

5. Drawn by. Identify the planning or process engineer.

The body of the operation sheet provides the detail of the necessary operations and inspections through the shop to complete fabrication, and where necessary, final assembly and test of the part being considered. Operation sheets are normally structured to provide the following data:

1. Operation Identification. Sequential numbering of operations necessary to process the part.

2. Required Description. Brief, concise definition of each operation.

3. Material Required and Quantity. Describe both type and quantity.

4. Parts Required and Quantity. This information identifies the number of previously fabricated parts which will be required for the part being planned.

5. Machine Assigned. Designation of machine to be used.

6. Jigs, Tools and Fixtures Required. Any production equipment to be used for fabrication or assembly. Tools required to provide the specifically desired manufacturing operation. The method of feeding, holding, positioning, and/or releasing the work may require use of jigs or fixtures.

7. Department. The department name or work center in which the work is to be performed.

8. Standard Time. Standard times determined by the company through use of accepted estimating methods.

Care must be used in setting standard times since these will be used later to establish machine and personnel requirements. Setting required times may be delayed if there is likelihood of routing change during later process planning. Regardless of when set, standard times must be established by persons qualified in the techniques used. The development and use of standard times are described elsewhere in this guide.

FACILITY ARRANGEMENT

After preliminary decision as to the flow patterns for work in the facility, thought must be given to the development of work facilities to conform with the selected flow patterns. The work station is the combination of equipment and people necessary to satisfy the requirements of an individual work task assignment. The individual work stations are combined, by either process or product arrangement, to form departments or cells which facilitate supervision and manufacturing planning and control. These departments are then combined to provide the total manufacturing facility.

In evaluating facility layout, certain conditions may be observed that indicate the facility arrangement is not as effective as it should be. Some of the symptoms of poor layout are shown in Figure 8-3.

- MATERIALS MOVE SLOWLY THROUGH THE PLANT
- MATERIAL HANDLING COSTS ARE HIGH
- LARGE NUMBERS OF INTERNAL EXPEDITORS ARE USED
- STOCKROOMS AND WORKPLACES ARE CROWDED
- WORK IN PROCESS IS FREQUENTLY DAMAGED OR LOST
- WORK MOVES IN ERRATIC FASHION THROUGH THE PLANT
- FAILURES TO MAKE SCHEDULES ARE COMMON

**Figure 8-3 Symptoms of Poor Facility Layout**

TECHNOLOGY TRENDS

A number of technology areas have been identified by DOD as having significant potential benefit to DOD systems. These are shown in Figure 8-4. In each case, the application of the technology will require that the underlying scientific problems in the technologies be solved. In addition, cost effective manufacturing processes must be developed if these technologies are to become part of real developed deployed systems. If the system performance forecasts are based on advanced applications such as those in Figure 8-4, the PM should ensure that manufacturing technology development is occurring in concert with the specific engineering development.

**Very High Speed Integrated Circuits**

**Focal Plane Arrays**

**Uncooled Detectors**

**MMW Seekers/Sensors**

**Multi-mode/multi-color seekers**

**Fiber Optics**

**Advanced Algorithms Processing**

**Advanced Warhead Concepts**
- **Aimable**
- **Explosively formed penetrator**

**Directed energy/high power MW**

**Low Observables**

**Passive Sensing and Detection**

**Satellite Navigation Systems**

**Figure 8-4 Future Trends in Technology**

## MANUFACTURING TECHNOLOGY

The objective of the DOD manufacturing technology (MANTECH), program, discussed previously in Chapter 4, is to develop or improve manufacturing processes, techniques, materials, and equipment to provide timely, reliable, and economical production of defense material. It is designed to "bridge the gap" between research and development (R&D) innovations and production. The MANTECH program was initiated to stimulate research in modern manufacturing systems, processes, and equipment with the goal of reducing system acquisition costs. It is a program to establish, validate, and implement advanced manufacturing capabilities for: 1) producibility, 2) productivity, 3) cost/price reduction, and 4) quality assurance. An important MANTECH program goal is to ensure that the results of laboratory research and development investments can be translated into the production of defense equipment at the factory level.

The MANTECH program is designed to stimulate effective industrial innovation by reducing the cost and risk of advancing and applying new and improved manufacturing technology. The integration of MANTECH and acquisition programs is illustrated in Figure 8-5. To obtain the maximum benefit on units manufactured using the improved technology, new manufacturing technology should be available, in proven condition, early in the production phase of a program.

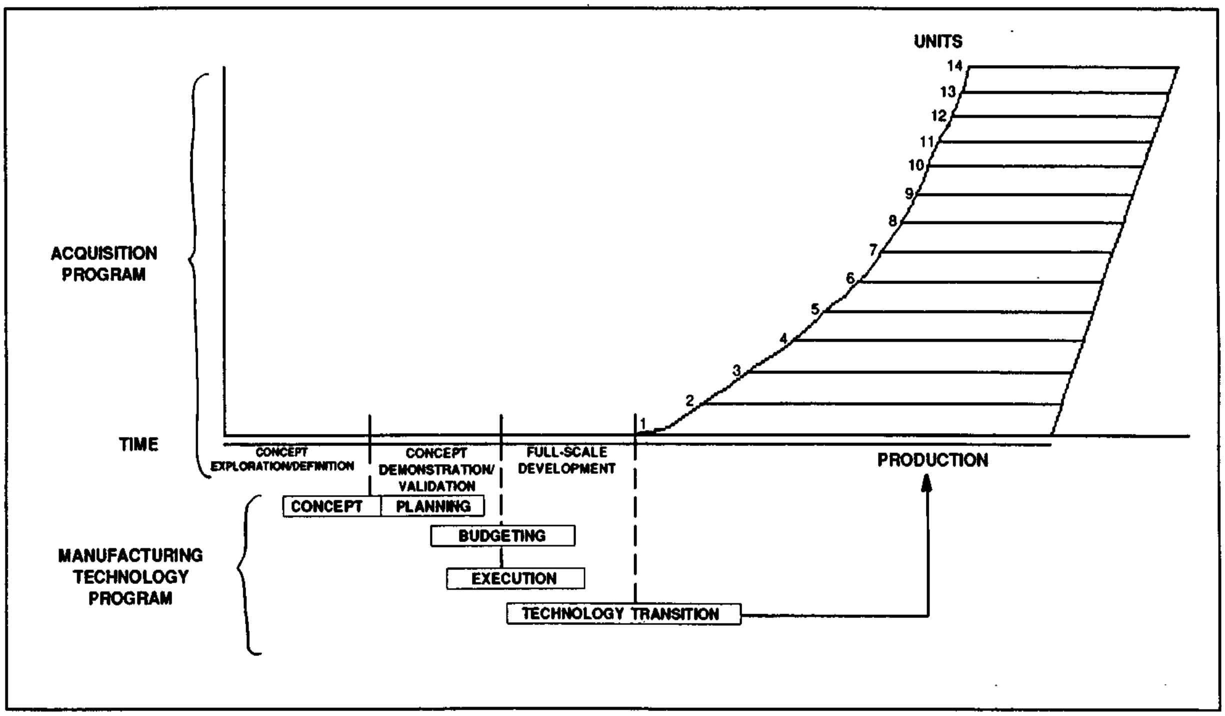


**Figure 8-5 Manufacturing Technology/Acquisition Management**

DOD funding of manufacturing methods and technology efforts is intended for projects which meet the following criteria:

- Satisfies a current or anticipated requirement for which manufacturing technology will increase general productivity.
- Not a duplication of effort of either government or private programs.
- Emphasis should be on development of processes, techniques, or equipment rather than R&D oriented efforts.
- State-of-the-art must have been demonstrated.
- Substantial benefit potential in three areas: 1) improve responsiveness to current and projected requirements, 2) improve the defense production posture, 3) reflect the most advanced manufacturing state-of-the-art.

Information concerning the MANTECH program and the results of the projects are made available through four methods.

First: End of Contract Briefings - Generally, MANTECH contracts require the contractor to demonstrate the results to its peers. A list of the tentatively scheduled briefings is compiled early each calendar year and distributed to the private sector through a number of societies and associations which interact with the Manufacturing

Technology Advisory Group (MTAG).

Second: Technical Reports - Each MANTECH contractor is required to prepare a technical accomplishments report. The Services distribute these reports to those companies known to be interested in the particular technology. In addition, copies are sent to the Defense Technical Information Center (DTIC), where the report is entered into a bibliographic data base. DTIC's bibliographic data base is accessible by remote terminals from many government and contractor locations throughout the country. In addition, those reports which can be released to the public for unlimited distribution are automatically sent to the National Technical Information Service (NTIS) by DTIC where they can be purchased by anyone for a nominal sum.

Third: The Manufacturing Technology Information Analysis Center (IAC) in Chicago is one of several Information Analysis Centers established by DOD in recognition that it might be difficult to find specific technical information within the vastness of the DOD community. This particular IAC focuses on manufacturing technology. It has on-line access to the DTIC data bases and has created its own data base for other literature. It has also produced technical reports of interest to the DOD MANTECH community such as "High Order Languages for Robotics" and "Uses of Artificial Intelligence in Manufacturing".

Fourth: Perhaps the most effective MANTECH program technology transfer vehicle is the organization known as the MTAG. This group provides inter-Service coordination of the MANTECH program. It consists of an Executive Committee and six Technical Subcommittees (Computer Aided Manufacturing, Metals, Non-metals, Test and Inspection, Electronics, and Ammunition). The MTAG maintains liaison with about a dozen industrial societies and associations throughout the year. The Subcommittees' interaction with the groups provides the opportunity for the technical experts to discuss and exchange information of mutual interest. The MTAG also holds an annual plenary meeting attended by MTAG members and the industry groups.

## INDUSTRIAL MODERNIZATION INCENTIVE PROGRAM (IMIP)

In the Defense industry, two problems have been cited most frequently as inhibiting modernization and progress in the productivity area. These are program uncertainties and a profit policy which, in certain cases, is based on cost. In the first instance, risks are introduced which hinder investment amortization and inhibit long term planning. In the case of the government's cost based profit policy, a contractor may actually see profits reduced as a result of efforts to improve productivity and reduce costs.

These factors have worked to accentuate what some have criticized as contractor management's emphasis on short term profits and maximizing return on invested capital. Return on assets has often been used as a yardstick in measuring corporate progress and executive performance. This management philosophy results in a reluctance to invest large sums of capital due to effects on the current financial balance sheet. Figure 8-6 graphically demonstrates the main problem in justifying cost reduction investments involving large outlays of capital. The problem is profits (cost savings/avoidances) do not increase in the short run, while costs (capital invested) increase significantly because capital must be invested in advance or "up-front" of the expected benefits. This phenomenon can lead to extremely conservative capital asset management, and long term productivity gains are often lost.

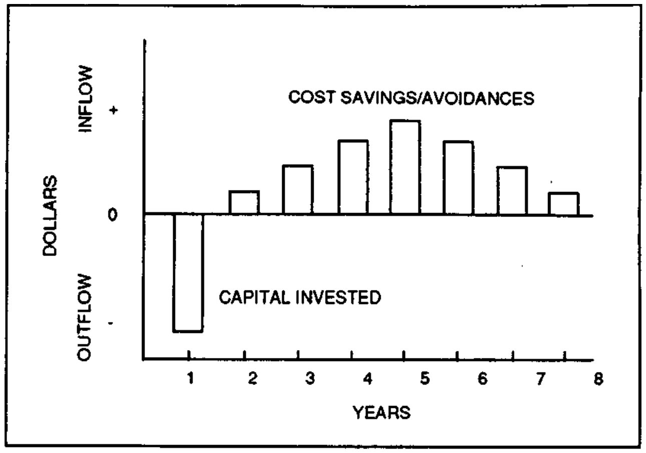


**Figure 8-6 Cost Reduction Example**

The IMIP provides a common framework for an extension of the military services' "TECHMOD" and MANTECH programs. MANTECH is a well established program with objectives which are in some ways similar to IMIP, i.e., making improvements in manufacturing productivity. But there are some very significant distinctions. The main focus under IMIP is to encourage contractors to make capital investments which will result in increased productivity, improved quality, reduced DOD acquisition costs and an enhanced industrial base. IMIP is aimed at improvements on a factory-wide basis, and involves both well established and state-of-the-art technology. Perhaps the most important distinction is that the main thrust of the IMIP is on contractor funding for investments.

The IMIP is intended as a tool to overcome the previously discussed impediments to increased capital investment. Under the IMIP, incentives can be provided to motivate a contractor to invest corporate funds which result in reduced acquisition costs. The idea is to negotiate a business arrangement with benefits to both parties that may not have been possible otherwise.

The principal incentives are shared productivity savings and contractor investment protection. The shared productivity savings allow industry to share in the savings which are a product of making these capital investments. The contractor investment protection permits amortization of plant and equipment through a contingent liability guarantee.

The Services and their program managers must continually identify programs where application of advanced technology would increase productivity, result in savings to the government and increase profits to the contractor. Some programs that have adopted advanced manufacturing practices have experienced significant results. The Air Force F-16 program is a classic example. A $25 million Air Force investment in advanced manufacturing technology was negotiated in conjunction with a commitment of the contractor to invest $100 million in severable plant equipment. The government provided termination protection for the $100 million contractor investment over 1158 aircraft. An agreement was made to adjust the contract target and ceiling amounts for savings according to a prescribed formula. An award fee of $1 million per year for four years was allowed. The potential F-16 manufacturing cost savings was calculated to be in excess of $370 million over 1388 aircraft, with the Air Force share of this savings in excess of $220 million.

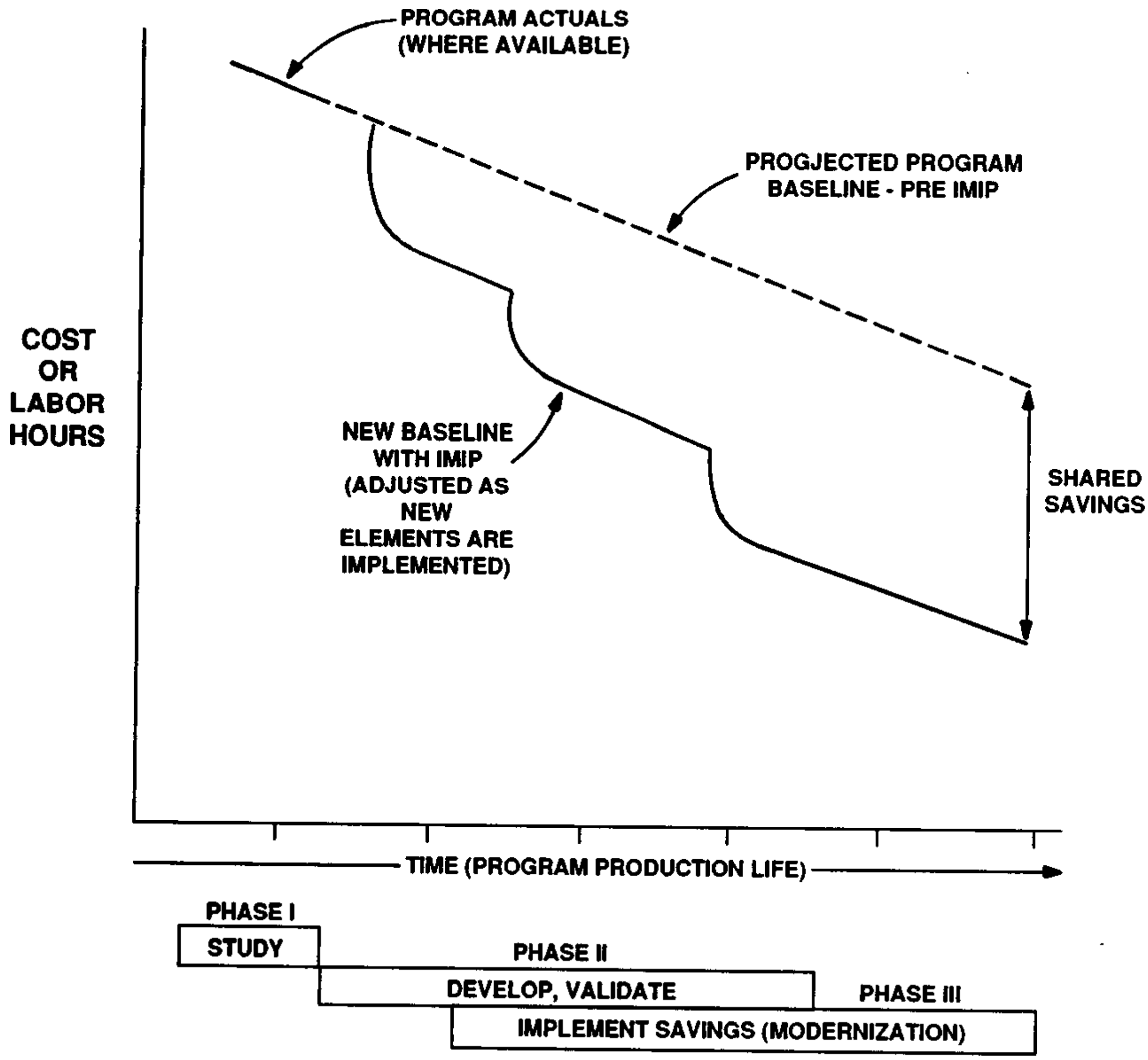


**Figure 8-7 IMIP and Program Baseline Adjustments**

Figure 8-7 illustrates the effect an IMIP would have on a program baseline. The program baseline, with and without the IMIP, is shown during its various stages, and the difference between the two as shared savings is shown.

The technical aspects of the IMIP are divided in three phases:

1. <u>Analysis and Planning.</u> This consists of identification of high cost manufacturing areas, analyses, and development of initial approaches to improve factory manufacturing. Analyses are made of advanced manu-

facturing technologies, contemporary equipment, quality assurance, production control, and management information systems. Cost saving potential, return on investment and conceptual design of factory layouts required to implement specific improvements are developed.

2. Technologies. This includes establishing and validating enabling technologies which are voids in the manufacturing state-of-the-art that must be overcome to attain higher levels of factory integration. A detailed definition of factory enhancements and a plan for accomplishing and implementing these into production must be developed.

3. Implementation. In this phase, detailed factory designs are completed and enabling technology programs are integrated into manufacturing operations. Advanced management information systems, manufacturing planning tools, and the cost analysis and performance assessment system are made ready for implementation.

FACILITY MODERNIZATION

The annual rate of productivity improvement in the United States is lower than any major industrial country of the Western World. This can be attributed largely to the fact that our manufacturing plants are operating with tools and processes that have not kept pace with emerging technology. The result is that we are losing our position as the world leader for production of manufactured goods of the highest quality. Peter Drucker, a founding father of the discipline of management, has called for a restoration of our international competitiveness based on three approaches: 1) moving to more automation, 2) the redesign of entire plants and processes as integrated flow systems, and 3) the integration of mini and microcomputers into our tools.

The technology exists for drastic advances in manufacturing processes and companies that have introduced innovative methods such as Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) or Computer Numerical Control (CNC) systems are experiencing phenomenal productivity increases. Advanced computer technology and the development of a theory of factory architecture has changed many old ways of doing business. The opportunity exists to start designing directly to the capabilities of our manufacturing and quality tools, rather than incrementally adapting a design to the limitations of a traditional manufacturing operation.

Not all of the obsolence that exists within the defense industry can be attributed to government policies. Nor is the use of standard equipment and tools which have proven their value over a great many years a valid indicator of an inefficient factory. Some changes are desirable; some should be undertaken with caution; but any change has to be justified in the eyes of the investor.

There is a continuing need for basic operations such as milling a flat surface; broaching a key slot; and number of casting, forging and forming methods which will not justify automating. Production requirements must justify the cost of special fixtures in order to realize a return on the investment. In a great many cases, general purpose tools, such as vises, will be adequate for securing parts during milling, drilling or grinding. Low volume printed circuit boards may be more economically supported with a foam pad than a Class A holding fixture, and hand assembly may be less costly than developing a program for mechanically inserting components in the board. The economics of lot size is a fundamental consideration in tooling and mechanization decisions.

Some processes seem natural candidates for numerical control. Spot welding, for example, has been automated in the auto assembly plant. However, a case where the part can’t be moved to the machine presents another set of conditions to be considered. Complete mechanization or automation may not be the most productive alternative in many plants due to quantity requirements, special product characteristics or a particular plant’s equipment inventory. In some cases the most attractive alternative may be to have the part produced in another plant or by another contractor. Economics is generally the basis for a contractor to subcontract to other companies and a critical consideration (as discussed earlier in this chapter) in any modernization or expansion program for a contractor.

The following factors should be stressed with the involved contractors: (1) adopt greater innovation in the use of materials and processes; (2) develop a strong link between manufacturing R&D and operations to ensure that technology which is ready for the manufacturing floor gets there; (3) initiate innovative approaches from the financial and contracting standpoint to develop risk sharing mechanisms effective over longer periods; and (4) make a commitment for capital investments to update obsolescent facilities and equipment.

Companies that utilize very few new manufacturing processes lack a potential for productivity improvement, a potential for lower cost manufacturing and increased profit-making opportunities. The high cost of failure scares off many firms and is the prime reason for management resistance to implementation of potentially money-saving projects that involve new, more expensive, and complex manufacturing equipment, controls, or processes. The Department of Defense has strongly advocated the utilization of advanced technology as a means of reducing manufacturing costs and to help in the resolution of other production base problems. DOD MANTECH and IMIP have as basic objectives the improvement of productivity and responsiveness of the defense industrial base by sharing with industry the risks and costs of establishing and applying new and improved manufacturing technologies.

A division of one of the larger U.S. corporations, while preparing to install what is reported to be the largest concentration of electron beam (EB) production welding machines in the world, developed a set of guidelines designed to minimize the risk associated with the new process implementation. The general nature of these guidelines is applicable to nearly any prospective new process application:

1. Experiment with as many process alternatives as possible. Make certain that, before the decision is made to select a particular new process, it is the optimal choice for the task that must be accomplished. Consideration should be given to reliability and maintainability, return on investment, productivity improvement potential, adaptability to design changes, and any special feature that would enhance the manufacture of the required product.

2. Advice from product design personnel must continually be sought during the decision process.

3. Obtain names of users of processes under consideration from equipment builders. Observe both successful and unsuccessful process applications.

4. Obtain from current users:
    a) Level of operator skill required,
    b) Level of maintenance skill required,
    c) Cost of “consumables”,
    d) Indirect labor required,
    e) Long term efficiency of the process,
    f) Most frequent causes of breakdowns,
    g) Expected number and severity of breakdowns,
    h) Cost of back-up tooling and maintenance items, and
    i) Rework and scrap rates.

PRODUCTION INNOVATIONS

New methods in manufacturing developed in recent years are drastically changing the production process, and the extent of their adoption will be the key factor for most companies to remain competitive. The advent of the computer has by far been the single factor that has most influenced the shift toward an automated factory system. Factory automation includes the use of such methods as: 1) numerical control machines, 2) transfer machines, 3) robots, 4) automated warehouse systems, and 5) material handling devices that are hardware systems for processing, handling, or storing factory products.

Technologically we are at the dawn of another industrial revolution brought about by the inexpensive computer power available through today’s electronic technology. The selection of processes driven by today’s technology are discussed in this chapter. Professor David Acker, DSMC, contributed the information on robotics, and computer-aided design and manufacturing which are included in this chapter as well as the information on automated systems discussed in Chapter 14.

The areas that lend themselves most readily to computer control or monitoring are the following:

a) Direct Process Control — Utilization of components for the direct control of machine tools, referred to as computer numerical control (CNC). Such a system usually contains a large computer as a part program generator, a medium-scale computer as the active supervisor, an interpolator that feeds data to a number of machine tools, and a minicomputer as the controller of each machine tool. Also, direct computer control is utilized for the control of conveyors, stacker cranes, plating operations, heat treat furnaces and many other factory operations.

b) Process Monitoring — Computers are used to collect data and provide reports to management on process parameters, machine utilization and maintenance status. Powerful minicomputers and more sophisticated hardware have created the ability to link computer hardware as a means of providing a broad-based plant monitoring and control system, referred to as distributed processing.

c) Testing and Inspection and Computer Aided Testing (CAT) — Computers test and automatically adjust electrical and mechanical components and assemblies. Performance statistics and overall quality reports can be provided to management.

d) Plant Management and Information Systems — Data collection systems use shop floor terminals for data originated from foremen, tool operations and other shop personnel. Data collection is often used in conjunction with the material requirements planning (MRP) function as well as with inventory control, scheduling, and work in-process reporting.

e) Engineering Support — Special computer aids to the manufacturing engineering function include interactive graphics systems for product and tool design and tolerancing, time study, machine tool capability analysis, line balancing, and group technology packages.

f) Environmental Control — Computer systems are used for monitoring and controlling heating and air conditioning, air and water purity, and power usage.

Successful factory utilization of the above control techniques requires a systematic planning process. Detailed planning must properly define the company's needs and apply the appropriate solutions to the problems. The following questions must be considered:

1. What is the present level of automation?

2. How well does the current system meet company needs?

3. What level of automation is needed to satisfy current demands, future growth and productivity requirements?

4. What are the system uses?
5. Where can the current system be used?

## ROBOTICS

Industrial robots, for the most part, perform simple, repetitive motions with some degree of precision. They perform such tasks as welding, forging, material handling, machine loading/unloading, palletizing, grinding, deburring, polishing, spraying, assembling, machining, inspecting, and packaging. Industrial robots have the potential to increase productivity, provide manufacturing flexibility, reduce manufacturing costs, and replace workers in hot, dirty, hazardous, monotonous, and fatiguing jobs.

### The Nature of Industrial Robots

In a factory, robots represent off-the-shelf automation. They fill the gap between special purpose automation and human endeavor. Practically speaking, they are machines that are capable of duplicating human skills and flexibility with both accuracy and precision.

The Robot Institute of America (RIA) defines a robot as “a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.” An industrial robot can control and synchronize the equipment with which it performs. With this kind of capability, it can eliminate the need for people to work in environment that may be dirty, dull, or dangerous.

Typical tasks assigned to robotics are shown in Figure 8-8.

**Palletizing**
- ☐ Glass
- ☐ Metal
- ☐ Plastics
- ☐ Bricks
- ☐ Ceramics
- ☐ Yarn
- ☐ Furniture parts
- ☐ Food products
- ☐ Toy products Housewares

**Spraying**
- ☐ Finish materials
- ☐ Fiberglass polyester
- ☐ Urethane, polyester foam

**Grinding/Deburring/Polishing**
- ☐ Metal parts
- ☐ Plastic parts
- ☐ Wooden parts

**Searching**
- ☐ Depalletizing
- ☐ Palletizing

**Machine Load/Unload**
- ☐ Die casting
- ☐ Injection molding
- ☐ Blow molding
- ☐ Thermoset molding
- ☐ Ultrasonic welders
- ☐ Inspection devices
- ☐ Stamping presses
- ☐ Machine tools

**Packaging**
- ☐ Loading into cartons
- ☐ Placing into strapers

**Post Operations**
- ☐ Degating
- ☐ Deflashing
- ☐ Rough trimming
- ☐ Quenching

**Assembly**
- ☐ Small to large plastic products
- ☐ Small to large metal products

**Tool Carrying**
- ☐ Spot welding
- ☐ Arc welding
- ☐ Drills
- ☐ Routers
- ☐ Staple guns
- ☐ Automatic nailers
- ☐ Flame drying guns
- ☐ Water jets
- ☐ Lasers

**Line Tracking**
- ☐ Automatic welding
- ☐ Glass handling
- ☐ Conveyer loading/unloading

**Forging/Foundry Handling**
- ☐ Upset
- ☐ Die forging
- ☐ Press forging
- ☐ Roll forging
- ☐ Swaging
- ☐ Heat treating
- ☐ Loading/unloading oven
- ☐ Handling parts through presses
- ☐ Flame cutting

**Figure 8-8 Typical Robot Tasks**

## Growth of Industrial Robot Installations

Although there are obvious advantages to installation of robots in our factories, U.S. industry has been relatively slow in adapting them. Reluctance to do so may stem from management’s perception that the average worker in a factory subconciously fears robots. Workers fear robots because, at first glance, they appear to be part of the ultimate scheme of management to eliminate workers from the work place. Actually, industrial robots represent a long awaited advancement. Ultimately, the robots will free workers from tasks that (1) present serious health hazards, (2) require human agility and mobility, but are mundane and/or repetitive, (3) require human skill, but which cannot be performed effectively for long periods of time because they cause fatigue. In the future, workers will not become obsolete, but some of their present skills will.

## Manufacturing Cost Distribution

It is important to recognize today’s manufacturing environment. Figure 8-9 presents a breakdown of typical manufacturing costs, by percentage. This breakdown is representative of the situation in defense, aerospace, electronics, and heavy industries in the United States. Materials account for the biggest “slice of the pie.”

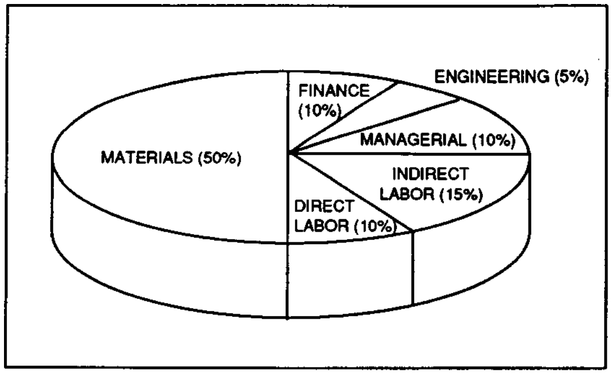


**Figure 8-9 Typical Manufacturing Cost Distribution**

The opportunity for reducing manufacturing costs by introducing robots has generally been in the area of direct and indirect labor tasks. With costs distributed as shown in Figure 8-9, the first inclination is to consider replacing direct and indirect labor with a robot due to the similarity of robot motions to human arm movements. However, the potential for cost savings is greater if ways are also found to use robots to save materials.

For many years robots were marketed as the answer to many of the problems faced by industry in the United States. U.S. industry was beset by (1) rising direct labor costs, (2) pressures to improve productivity, (3) challenges posed by environmental and occupational health and safety authorities, based upon unpleasant and hazardous working conditions, and (4) need for better product quality. A modest, but increasing number of robots have not only been able to solve these problems, but have been able to save materials and provide a manufacturing flexibility not available previously.

Robotic Integration

Industrial management generally recognizes that factories need to be designed as systems. Unfortunately, about three-quarters of the new robots are being integrated into existing production lines. The robots are not being made a part of a new "system," i.e., a manufacturing center composed of cells, each having several work stations. Robots will gain wider acceptance if they become a part of such work cells in manufacturing centers instead of becoming just another piece of equipment in an existing production line. The centers provide significantly greater efficiency, flexibility, and effectiveness in manufacturing operations than do the production lines of older factories.

In the factory the hard-technology view and the soft-technology view should form a global perspective of manufacturing systems. The hard-technology view will focus on the production of the product. This view will be represented by centers with cells containing robots and the other processing equipment as just discussed. The soft technology view will focus on communicating the requirements for monitoring, controlling, and reporting the status of the systems. In other words, the technical and business systems will be integrated to become a part of the overall manufacturing system. If we understand this concept, then we can recognize why far-sighted industrial management is inclined to be more concerned with manufacturing centers than with individual robot applications.

Robots are justified within the production volume ranges shown in Figure 8-10. When less than 200 parts are to be manufactured per year, manual labor is usually less costly. Above 20,000 parts per year, hard automation is generally more cost effective.

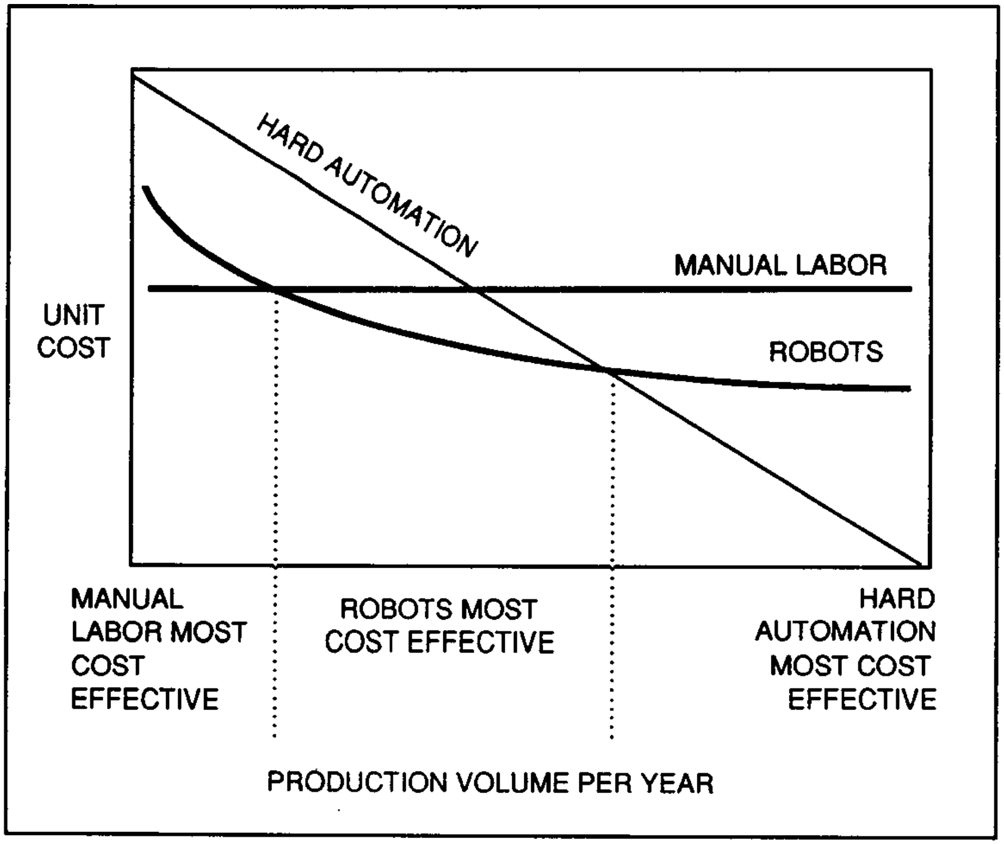


**Figure 8-10 Comparison of Manufacturing Method Unit Costs, By Level of Production**

Today, about 80 percent of the U.S. industrial robots are being applied to welding, material handling, and machine loading/unloading. The remainder of the robots are being used in such activities as spraypainting, machining, assembling, and palletizing. About 40 percent is divided almost equally between foundries and the light manufacturing industry that is producing nonmetal products. The remainder of the applications are in the heavy equipment, electrical/electronics, and aerospace industries.

Over the years, the capabilities of robots have continued to increase. Much of the current robot technology was unknown just a decade ago — particularly control technology and programming. Now, robot manufacturers have discovered electronic logic and computer software. These technologies are making robots adaptable to an increasing variety of complex tasks. Therefore, it is very important that each proposed application be carefully considered and that the robot selected be properly engineered to ensure success. Such a robot will inherently increase manufacturing flexibility and improve product quality and productivity.

<u>Impediments to Application of Robotics</u>

James Albus of the National Institute of Standards and Technology indicates there are six problems associated with robotics that have to be solved. The problems are identified below:

1. <u>Structures.</u> The structures of robots will have to be made sufficiently stiff and rigid to overcome the funda-

mental problem of accuracy and repeatability.

2. Sensing. Robots in the factory will have to be able to see, feel, hear and measure the position of objects in many different ways. Therefore, the data from sensors will have to be processed, and information extracted that can be used to successfully direct robot actions.

3. Control. Robots with sensors will have to be able to accept feedback data at a variety of levels of abstraction and have control loops with a variety of loop delays and predictive intervals.

4. World Model. Robots will have to store and recall knowledge of the world about them that will enable them to behave intelligently and show some insight regarding the spatial and temporal relationships inherent in the work place.

5. Programming Methods. The techniques for developing robot software will have to be improved.

6. System Integration. Robots will have to be integrated into the overall factory control system.

Fortunately, the technical problems are amenable to solution. However, until the problems are solved, robot capabilities will be limited and robot applications will continue to be relatively simple.

Today, robots can handle parts that are similar in size and orientation, and placed in the same general location. And a few advanced state-of-the-art robots can "look" for a part. However, future robots will be able to find specific parts with "TV" eyes and orient the parts as required. Also, sophisticated sensors will be able to "feel" the difference between various part sizes and/or orientations. A memory, linked to the eyes, will be able to tell the arm which part to select. Further, robot memories will help in sorting out and removing wrong or broken parts. The major problem that has to be overcome, before these advances are possible, is to reduce the cost of vision sensors. Presently, the sensor cost start at about $120,000. This is usually too high a price to pay, if one takes into consideration the length of the payback period.

## OVERVIEW OF COMPUTER AIDED DESIGN AND MANUFACTURE

CAD - computer aided design - represents the merger of computer technology with mechanical drawing. The three essential functions that can be better accomplished with CAD are: line drawings that can be created and stored for future reference; libraries of common symbols used to create line drawings that can be easily accessed; and plotting and dimensioning functions that save numerous hours of manual drawing and computation and establish a database for future reference.

CAD represents a significant advance over manual design work in three subareas: geometric and surface construction, three-dimensional modeling, and structural or stress analysis. Manual design analysis requires extensive generation of mathematical formulas to describe a surface or shape. With a manual system, stress factor calculations are accomplished by the computer. With CAD graphics systems, the input process is aided significantly by the computer, and the resulting analysis data are presented graphically on the system screen, a significant advancement.

Computer aided manufacturing (CAM) has five subsets: production programming, manufacturing engineering, industrial engineering, facilities engineering, and reliability engineering.

Production programming involves the preparation of numerical control tapes or patterns to be used in the manufacturing process. Manufacturing engineering relates to the design of the product and the tools necessary for actual production. Industrial engineering involves analysis of labor and equipment utilization and process control considerations. Facilities engineering involves equipment design and plan and equipment layout. Reliability engineering is concerned with quality control, coordinate measuring, and failure analysis. These components of the manufacturing process represent a major opportunity for the use of CAM graphics systems.

Computer integrated manufacturing (CIM), is an extension of CAD/CAM. CIM utilizes the database created through computer aided design. The manufacturing control subsystem interfaces with numerically controlled machines, makes quality assurance checks during process manufacturing, and compiles time and attendance records. Computer integrated manufacturing links computer aided design and manufacture. A corporate database unites business data processing; computer-aided designs and reporting and control of manufacturing operations, including material control, quality assurance, and shipping and billing.

Computer aided design (CAD) and computer aided manufacturing (CAM) systems comprise a class of computer-driven systems that offers the potential for significant productivity gains in specific areas of manufacturing and other labor-intensive design and documentation.

Graphics systems are available for integrated circuit design; design of automotive, aircraft, and other manufactured parts; numerical control applications; design of plants in automotive and aircraft industries.

The CAD/CAM concept has gained quick acceptance in the industrial and design services marketplaces due to the resulting immediate gains in productivity. In addition to direct cost savings, CAD/CAM graphics systems can be justified on the basis of greater accuracy, application to automatic manufacturing processes, the reduction of errors through automatic error-checking procedures, reduced design turnaround time, uniformity of design quality not achieved through manual procedures, and reduced dependence on highly skilled and highly paid engineers for design. Three major advantages for users of CAD/CAM graphics systems are centralized database creation, data extraction capabilities, and documentation of engineering drawings.

The strong demand for CAD/CAM systems is due to four factors. First, productivity is increased from 3-10 times, depending on the task to be performed. Second, the lack of trained draftsmen and technicians is partly compensated through the use of turnkey systems. Third, the systems can produce more complete and better quality designs than existing design teams can produce. Fourth, use of the CAD/CAM systems eliminates repetitive routine tasks for designers.

## Computer Aided Design

As currently applied in the defense industry, product design engineering utilitizes computer aided design (CAD) to provide descriptive geometry on an interactive graphics terminal. This essentially allows the designer to shape/size/dimension a given part via the computer. CAD is currently moving into Phase III of its evolution. Phase I can best be characterized as the descriptive geometry phase. Phase II added three-dimensional oriented methodologies to provide visualization that facilitates the design effort. Phase III will encompass three-dimensional physical part modeling along with the analysis and simulation tools to allow the designer to “stress and test” the design before finalization.

Figure 8-11 illustrates the interrelationship between conceptual design, preliminary design, and production design. The shaded area through the middle is currently accomplished through CAD. As CAD moves into Phase III the unshaded tasks will be accomplished “real time” through CAD and the associated computer aided design analysis.

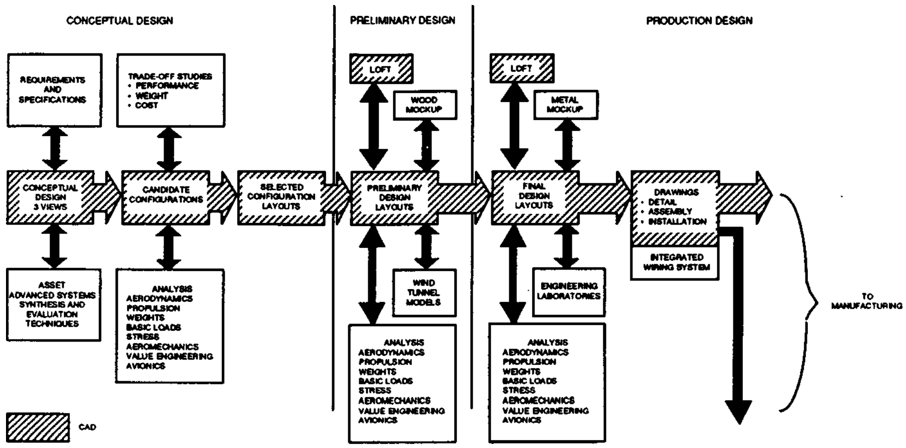


**Figure 8-11 Interrelationships of Discrete Design Phases**

CAD has shown impressive payoffs in productivity as compared to manual methods. Among the reasons for enhanced productivity are: complex constructions can be done faster with a computer; repetitive construction entities do not have to be redrawn, but can be instantaneously called from storage; geometric constructions are performed by the computer and do not have to be calculated; and the concentration of a designer on the video screen in an interactive mode is more intense than the designer is able to sustain on the drawing board.

Computer Aided Manufacturing

Computers have also been widely applied to manufacture and the term "computer aided manufacturing" (CAM) is used to describe manufacturing procedures that use computers to assist in the planning and production process, from inventory control to the programming of machine tools.

Like CAD, CAM applications are almost limitless. Among them are computer aided process planning (CAPP) to standardize and optimize production methods by transferring decision making to the computer. Also, a very close cousin to CAM is computer aided material planning and processing (CAMPP) which eliminates much of the labor intensive effort associated with these tasks. In the material planning and purchasing, the ultimate step in computer automation would be CAD generated data in a centralized product definition data base which purchasing could access such that purchase planning and order writing could be accomplished automatically.

Computer Aided Design and Computer Aided Manufacturing

Combining CAD with CAM (CAD/CAM) is the most active manufacturing initiative today, ahead of Flexible Machining Systems (FMS) and even group technology. An accurate in-depth understanding of CAD/CAM, however, has fallen behind the popularity of the term. It really means integrated product engineering and manufacture in the broadest sense of the word. Too many users today have settled for CAD, or worse yet, a small segment of CAD such as computer graphics. Similarly, some have seen CAM as numerical control (NC) tools; others have seen it as manufacturing resource planning (including material requirements). Fortunately, now these people are extending the limits of their thinking. They are looking to the high pay-out from the synergism of an integrated manufacturing system.

CAD/CAM can revolutionize industrial production. CAD/CAM has been known to cut the entire design, drafting, manufacturing process time by factors of four, five and even more. The companies that have pioneered with this revolutionary tool have found that many parts can be produced from start to finish by CAD/CAM; in some cases, drawings and paperwork have been eliminated entirely. Overall lead time has been reduced by as much as two-to-one, and design time by five-to-one. It has also been found that the efficiency of the approach has reduced computing time itself by 25 percent. Designs are improved because more alternatives can be evaluated and communications have been improved throughout the design/manufacture process. CAD/CAM can have a major impact on management by providing better information on the use and productivity of capital.

Figure 8-12 is a schematic layout of the CAD/CAM process illustrating the functions and procedures that take place. Computer aided design is a system for the design, problem solving and drafting phases of engineering. This system provides computerized input to the manufacturing process and its prime mission is the manufacture of engineering drawings. A graphics console (Interactive Computerized Graphics (ICG)) terminal (consisting of a special keyboard, cathode ray screen and a cursor control) provides rapid drafting capability. After solving design problems such as strength, weight, noise, vibration, etc, engineers construct a mathematical model of the product's geometry and store it in the computer Geometric Data Base (GDB).

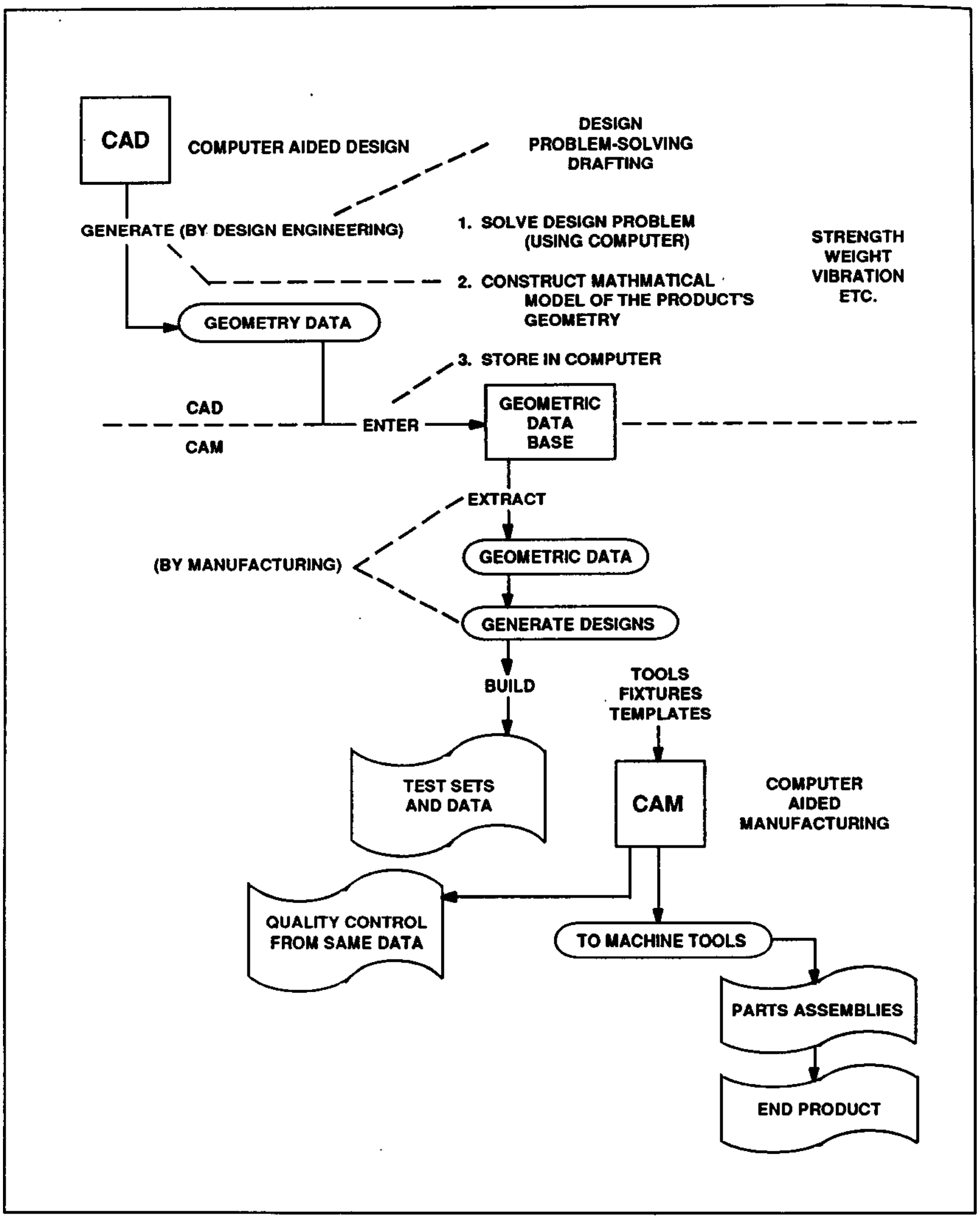


**Figure 8-12 CAD/CAM - How It Works**

The next step is the start of the manufacturing cycle. Tool programmers or part programmers retrieve a drawing previously created by the design engineer and stored in the GDB. A part program is developed using a large, arithmetically powerful computer as a part program generator. The program is then fed to a smaller, medium-scale computer that performs the functions of active supervisor and interpolator, feeding data to the controller of machine tools. Parts and even complete assemblies, are produced by instructions from the part program with constant monitoring to ensure that established tolerances are maintained. The results are a higher work quality and a much more efficient manufacturing operation, since errors are reduced to a minimum, and scrap parts are all but eliminated.

The requirements for CAD/CAM utilization within a defense contractor company are threefold:

1. Strong leadership must exist within the firm. Decisions to adopt CAD/CAM will mean large, initial outlays of capital. Long term dedication and support by top executives is essential.

2. There must be a willingness of management to take the risk of innovation. Upper management must be convinced the bottom line risk of new technology is not too great.

3. Imaginative government policies to stimulate production initiatives are required. The contract provisions, discussed in the MANTECH section of this chapter, under which the government assumes a portion of the risk is a first step.

The services must continually identify programs where application of computer and advanced machine tool technology would increase productivity, resulting in savings to the government and increased profits to the contractor.

Computer Integrated Manufacturing System

An important element of a computer integrated manufacturing system (CAM) is the business information system. Illustrated in Figure 8-13, this is the system that serves the information needs of the entire business.

## BUSINESS PLANNING AND SUPPORT

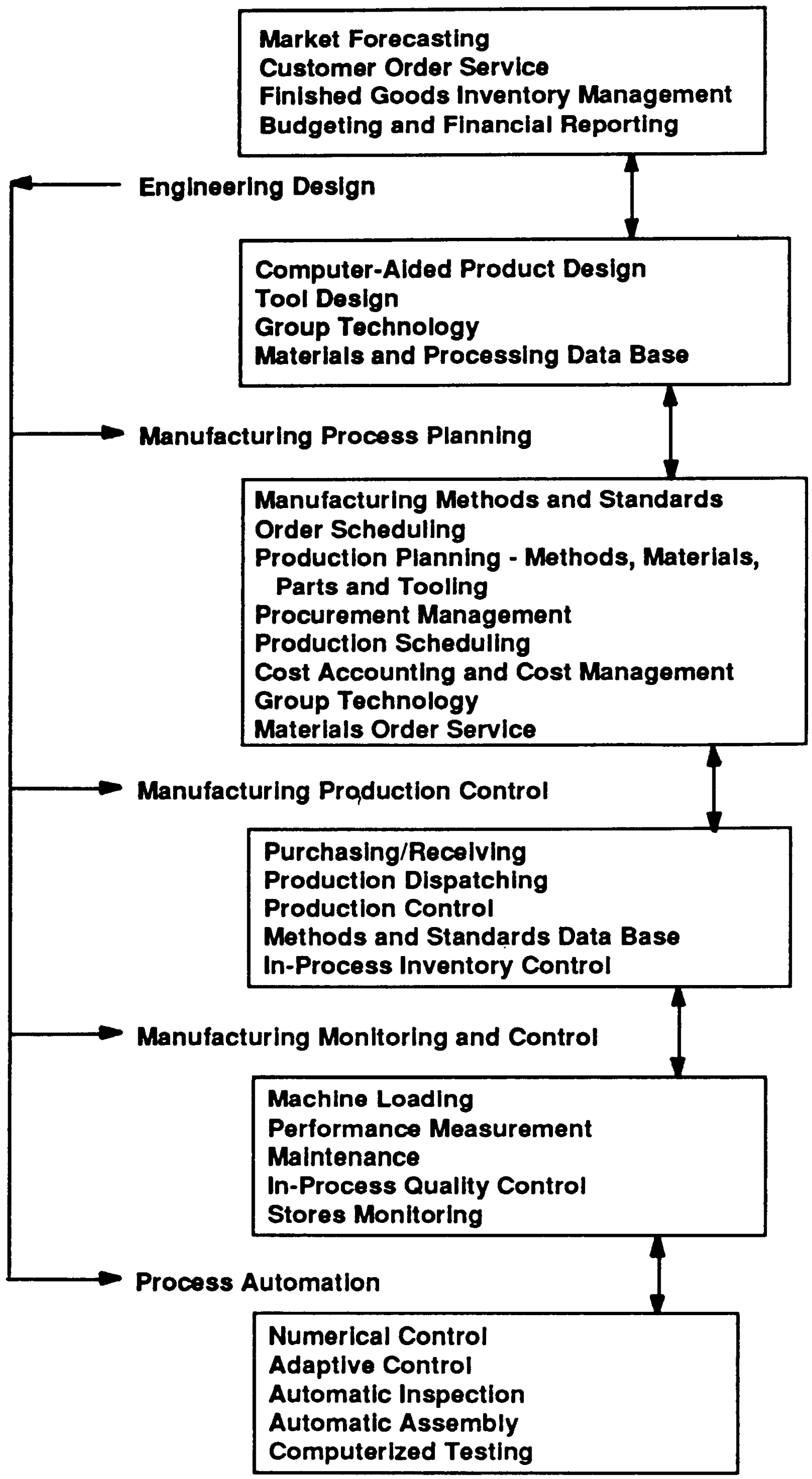


**Figure 8-13 Integrated Manufacturing System**

Another element of a computer integrated manufacturing system (CIMS) is the data base management system. This has been talked about and under development for twenty years, but only in the late 1970s did it become a practical reality. It is a powerful set of software programs that control complex file structures with a practical balance of integrity, security, resource costs, and ease of understanding. These elements and the CAD/CAM inputs are no longer separable; they must function together in a smooth running, total system. Together, these three are called "Computer Integrated Manufacturing," (CIM) integrating all of the manufacturing related functions into one neutral monolithic computer system. This is going well beyond the traditional CAD/CAM concepts, and really extending the limits of today's systems.

The ultimate payoff of CAD/CAM in the defense industry will occur when the geometric definition and other product definition information are defined and stored in a data base which can be accessed directly by manufacturing in order that the large variety and number of manufacturing operations can benefit in "real time" from this product definition. Advances have been somewhat impeded by traditional methods and the nature of the engineering/ manufacturing interface. Real success has resulted from the introduction of computer systems with data bases shared by both engineering and manufacturing organizations. It has been demonstrated, in a very practical way, that if the engineering organization can define or describe a new weapon in terms of standardized machine language, that same machine language can be used directly by manufacturing in the creation of tooling, jigs, fixtures, and other means of production, as well as for quality control functions and the operation of numerically controlled machines. Virtually every major U.S. defense contractor is involved in various facets of modernization and productivity enhancement. In anticipation of the dramatic changes sweeping through the civilian defense establishment, the U.S. Air Force has stepped in and committed millions of dollars to bring order and consistency to the multi-billion dollar, industry wide automation effort. A similar effort in the electronics industry, entitled ECAM, is being sponsored by the U.S. Army with the support of a large industry coalition.

There are economic advantages to be derived from the integration, or at least the interfacing, of computerized engineering and computerized manufacturing systems. Thus, it logically follows that the benefits of generative planning can be derived from these common systems. Generative planning interactively interfaces the design engineer with the computerized system in such a way that the designer is not only able to optimally design a part, but concurrently subject that part to a performance evaluation, and plan for the most economical fabrication of the part within the constraints of time schedules, availability of raw materials, and the variability of materials or manufacturing processes. Upon conformance of the proposed part to the performance objectives, part production may then be automatically introduced into a computerized fabrication, assembly, and inspection system. Printed circuit board and integrated circuit manufacturing are the best examples of current efforts to utilize generative planning. It is not uncommon in the electronics industry to go directly from a computer simulated product design to production without an intermediate prototype or preproduction model.

A number of experimental generative planning systems are now undergoing development and testing, but it is expected that it will be several years before such systems are common in any except the electronics industry.

It is generally recognized that weapon developments are often "time paced" by machine part structural elements. CAD and CAM offer the best solution to this problem by significant reductions in engineering and manufacturing planning/tooling flow times on critical tasks. CAD has demonstrated a greater potential for reducing programming time for parts fabricated on 3, 4, or 5 axis machines.

The time planned to coordinate, tool proof, and produce an NC machined part has been cut in half. An additional non-quantifiable, but equally important, benefit of CAD is that the designer can spend more time thinking about a technical problem and less time on mundane measuring, coding, and data preparation tasks. Also, the designer's ability to immediately review loft drawings on a video screen results in significant savings by avoiding the time required for inputting curve fitting programs. The continuity of the interactive iterative process allows many more trials to be made while eliminating time required for manually coding each new trial.